# Implementation of Energy and Power Saving Scheme in The Avenues Mall

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## ABSTRACT

This paper presents the results on an energy audit and subsequent implementation of energy efficient operation and maintenance strategies between April 2008 and March 2009 in Phase 1 of the Avenues mall with total area of 170,000 $m^2$. It has cooling production system with a capacity of 7200 RT and prior to energy audit, its peak power demand was close to 15 MW and annual energy consumption was 84000 MWh/y. Overall reductions of 9919 MWh/y in the annual energy consumption and 345 kW in peak power demand were achieved. The major contributors for the savings were time-of-day control for the air-handling units and lighting and optimization of chilled water flow. The project facilitated a benefit of 19838 KD/y to the Mabanee and company. More importantly, it achieved financial benefits to the Ministry of Electricity and Water of nearly 160,000 KD for reduction in power generation and transmission equipment cost and 372000 KD/y towards reduction in annual electricity subsidy in addition to an environmental benefit of reduction in CO2 emissions by 6940 t/y.

Key words: Energy audit, time-of-day control, peak power demand reduction.

## INTRODUCTION

Public and commercial buildings are the large consumers of energy anywhere in the world. Energy is used for heating, ventilation and air-conditioning (HVAC), lighting and other services. In Kuwait, air-conditioning (A/C) and lighting in buildings together account for 85% of the annual peak load demand and over 65% of yearly electricity consumption (Marafie et al., 1989). Energy auditing, followed by implementing energy efficient operation and maintenance strategies (EEO&MS) has been found to achieve savings in buildings' energy consumption exceeding 20% in governmental and institutional buildings (Maheshwari et al., 1997; Al-Ragom et al., 2001; Al-Ragom et al., 2005) and close to 10% in commercial complex (Al-Ragom et al., 2005).

This paper presents the details of an energy audit conducted in Phase I of the Avenues Mall, owned by Mabanee Company S.A.K., and the energy savings achieved by the implementation of EEO&MS for the A/C, ventilation and lighting systems, thereafter, between April 2008 and March 2009. Besides achieving considerable reduction in energy consumption, the project provided an opportunity for training Mabanee staff involved in building management, operation and maintenance in a number of areas such as procedures for conducting energy audit in the A/C buildings, and methods for evaluation of A/C plant operation and maintenance practices. Also it highlighted serious deficiencies in the design and operation of A/C, ventilation and lightings systems that need to be taken care of for ensuring the energy efficiency, thermal comfort and indoor air quality in the mall. The Mabanee staff, while interacting with Kuwait Institute for Scientific Research (KISR) team learned to ensure implementation of EE O&MS in the Avenues mall and other Mabanee buildings. Also, the experience gained by senior Mabanee staff will help in incorporating energy efficient design and operation features in their new buildings.

## BUILDING DESCRIPTION

The Avenues mall in Kuwait is considered the largest mall and one of Middle East's premier retail and leisure destinations. It has been designed to reflect the natural forms and elements of the desert with its flowing architecture and has set new standards in contemporary building and its dazzling addition to the retail landscape of the Arab world. The Avenues was built using environment friendly techniques, i.e., the maximum use of natural light and substantial energy saving. The main feature of the complex is the large skylight area that allows good daylight penetration in the complex.

The Avenues mall phase I with a total area of 170,000 $m^2$ opened in 2007. Its two stories structure houses over 150 lifestyle shops, restaurants, Cineplex, Carrefour hypermarket and an IKEA showroom. The shop's working hours are from 10:00 to 22:00 h from Saturday to Friday, while the cinemas-operating hours are from 11:00 to 3:00 h.

Also working hours are different during some special events such as Hala February, Ramadan Festivals and some special promotions. The annual energy consumption in the mall prior to energy audit was 84000 MWh/y and its peak power demand was close to 15 MW. Baseline power demand profiles for the typical summer and winter were as shown in Fig. 1.

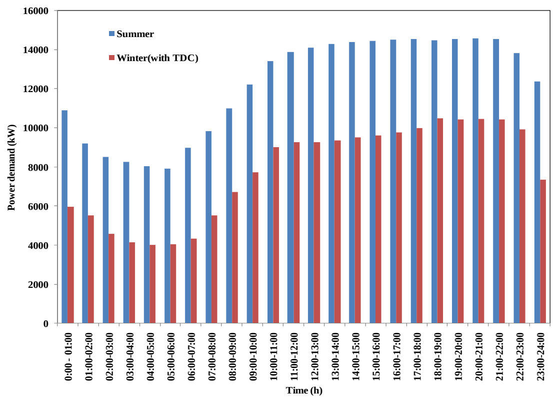


Fig. 1. Baseline power demand profiles for the Avenues mall.

## DESCRIPTION OF MAJOR POWER CONSUMING SYSTEMS

Ventilation and air-conditioning (VAC) system and the lighting system were identified as the two most power consuming systems in the Avenues mall. The VAC system is a 7200 RT chilled water system incorporating eight chillers with centrifugal compressors and water-cooled condensers (Fig. 2). The total connected load of the VAC system for cooling mode (summer season) is 9910.8 kW. A salient feature of the VAC system is the use of primary, secondary, and tertiary chilled water pumps to keep the auxiliaries power demand in line with the cooling production with the help of variable frequency drives (VFD) for secondary and tertiary chilled water pumps and use of two-way valve for load control for all users.

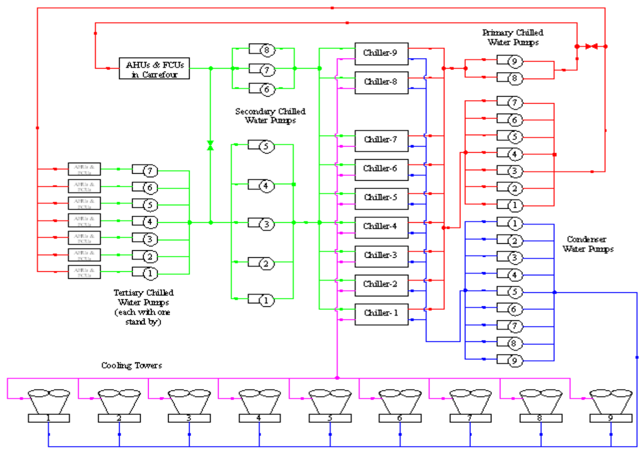


Fig. 2. Schematic diagram of cooling production system at the Avenues mall.

Lighting system comprises modern technologies such as T5 fluorescent and metal halide lamps with electronic control gears (ECGs). Such a lighting system saves energy and has prolonged lamp life. Also, huge skylights in many parts of the mall provide day lighting and good ambience besides saving energy. During the night, the mall is lit with 150-W metal halide flood lights fixed to the ceiling, and the hallways are lit with 2x35-W T5 fluorescent lamps and 35-W metal halide lamps. Also, the internal corridors are lit with 28-W T5 wall wash fluorescent lamps, and the service corridors and emergency exits are lit with 4x18-W T8 lamps. The total lighting load excluding the shops and tenants is 346.8 kW.

## APPROACH AND METHODOLOGY: ENERGY AUDIT

A working group comprising of facility manager from Mabanee Company S.A.K, operation engineer from A/C contractor and KISR staff was formulated. The tasks performed by this group are described below:

### Familiarization with VAC and Lighting Systems and their Ongoing Operation Schemes

This is a major task of the energy audit study and the success of an energy audit to a greater extent depends upon proper execution of this task. To be conducted jointly with the formulated group, it involves collection of energy consumption patterns of major components of the VAC and lighting systems and identification of components whose energy consumption can be curtailed, either by reducing their numbers in operation and/or restricting daily, weekly and seasonal duration of their operation.

Efforts should be made to gather as much information as possible for all major and minor consumers. Likewise a thorough study of the occupancy pattern should be carried out and the non critical areas where the time-of-day control (TDC) can be implemented should be identified. Furthermore, an assessment of facilities in building automation system (BAS) should be carried out to effectively monitor and control the operation of VAC equipment and lighting system.

Identification of Energy Efficient Operation and Maintenance Strategies

EEO&MS were identified for VAC and lighting systems. Identification of EEO&MS for the VAC system was guided by the findings of energy consumption patterns by its major components. Cooling production with a share of 63.9% accounts for more than half of the total energy consumption. Likewise, air distribution system with a share of 24.1% for the half of the remaining half. The balance of one quarter is mainly accounted for by the cooling distribution system (Al-Hadban et al., 2010). Accordingly the EEO&MS for the VAC system were based on the approaches as follows:

- Implement TDC operation for air distribution system in relation to the building occupancy,
- Reduce operation of secondary and tertiary pumps in line with the cooling production, and
- Optimize operational parameters of cooling production system.

For the lighting system, TDC was in practice in many parts of the mall including some areas under the skylight. Nevertheless, the lights in the corridors and lobbies were switched on 24 h year round regardless of the amount of daylight available in the area. Also, during the day, illumination levels in some areas were very high and there was a scope for reducing the artificial lighting electricity consumption. The potential EEO&MS for the lighting system showed the following:

- Effective use of daylight in the hallways,
- Replacement of halogen lamps with more energy efficient cool beam halogen lamps, and
- Use of occupancy sensors in low occupancy areas.

RESULTS AND DISCUSSION

Time-of-Day Control for VAC System

Implementation of TDC for the fans of AHUs was carried out in July 2008. The power data before and after the TDC are shown in Fig. 3. For the base case, the lowest power demand of 2000 kW was between 2:00 and 6:00 h, and it increased sharply, reaching above 4000 kW by 11:00 h. Thereafter, the increase was gradual, and the peak load of little over 4500 kW occurred at 22:00 h. Between 22:00 h and 2:00 h, the drop was sharp as well. As the measured power was higher than the connected load of all AHUs, it was obvious that the eleven MLTPs used for monitoring the power of AHUs were feeding several other consumers as well. It was assumed that the implementation of TDC for AHUs did not alter the power demand pattern of these miscellaneous users. On a typical summer day, implementation of TDC for AHUs realized a direct saving of 5.47 MWh/d by closure of fans. This saving was little over 60% that of the expected reduction (Fig. 4) (Al-Hadban et al., 2010). Also, there was an additional indirect energy saving of 0.85 MWh/d, because of reduction in heat added in the air stream due to air pumping process. These savings could be increased by 66.7% to 10.6 MWh/d by ensuring a better implementation of TDC.

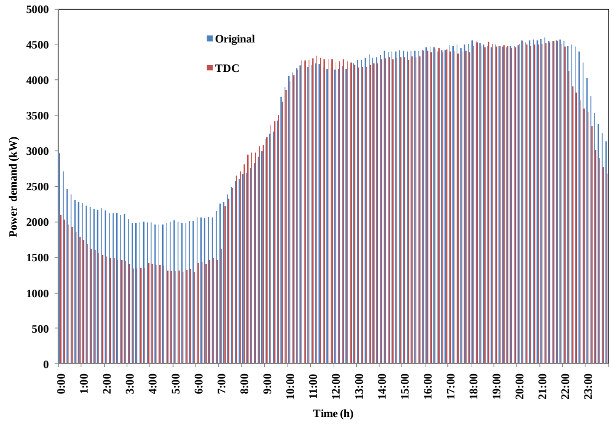


Fig. 3. Power demand patterns before and after implementing TDC for AHUs.

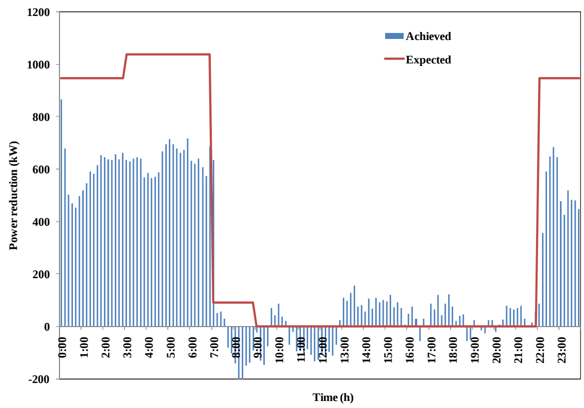


Fig. 4. Actual and expected reduction in power demand by implementing TDC.

Furthermore, closure of fans of AHUs resulted in complete closure of cooling supply to the specified zone, thereby, instantaneously reducing the load on the cooling production and distribution system and minimizing their power demand. The impact of the reduction in the cooling production due to closure of AHUs was measured by comparing the power demand patterns of the plant room for the 1st and 24th of July (Fig. 5) and for a typical summer day it was found to be 7.77 MWh/d.

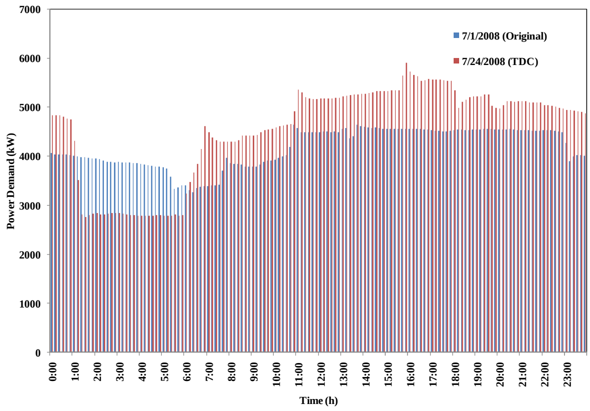


Fig. 5. Impact of TDC in power demand patterns of the plant room.

Implementation of TDC for AHUs was followed with monitoring of the indoor temperatures in different parts of the mall. Altogether 42 portable sensors, 18 in the shops and 24 in the public areas, were used. Typical temperature profiles before and after implementation of TDC for the public area is shown in Figs. 6. Prior to TDC implementation, temperatures in both shop and the public areas were lower during the night, reaching their lowest values at around 7:00 h. Thereafter, a gradual increase in space temperature was recorded, and it peaked at around 15:00 h, following the pattern of the ambient temperature. Interestingly, the pattern of increase in space temperature during the occupancy period was similar with and without the TDC, although with the TDC, the maximum temperatures were generally recorded at the end of the TDC duration. Although Avenues management did not allow monitoring of temperatures in cinema, it is more than likely that the TDC would have assured more comfortable conditions during night shows, since without the TDC, the lowest temperatures in several locations in public areas and shops fell below 22 and 20°C respectively. With the TDC in the public areas, the average of the lowest temperature was up by 0.7°C; while the average of the maximum temperature was higher by 1.0°C. Nevertheless the maximum temperature nowhere exceeded 28°C in public area.

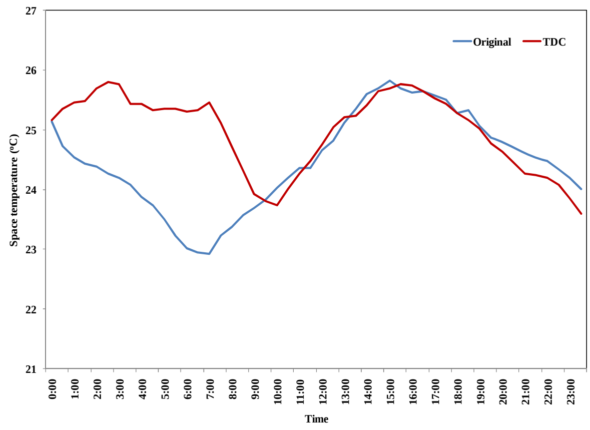


Fig. 6. Hourly profiles of space temperature in public area.

The annual energy savings achieved due to closure of the fans and reduction in cooling demand are 2699 and 1557 MWh/y, respectively. Thus, the total savings of 4256 MWh/y were achieved leading to a reduction of 5.1% in the baseline annual energy consumption. These savings could be increased to 7757 MWh/d by ensuring a better implementation of TDC. Furthermore, TDC implementation not only helped energy conservation while maintaining the comfort conditions during the occupancy period, it also avoided extremely lower temperatures during the non occupancy period.

Optimization of Chilled Water Flow

Chilled water distribution network in the Avenues mall comprises three circuits. Each chiller has its dedicated chilled water pump, referred to as primary pump. Additionally there are secondary and tertiary pumps with variable frequency drives (VFDs) (Al-Hadban et Al., 2010). The design chilled water flow is for a temperature differential of 7.78°C unlike a common practice of 5.56°C in Kuwait and worldwide. The reduced chilled water flow in the system is expected to reduce the pumping power by 28.5%. However the power rating of the combined chilled water pumps of 0.18 kW/RT would be over two and half times as compared to the recommended value of 0.07 kW/RT (Maheshwari et al., 2000). Nevertheless, use of two-way valves for load control in combination of VFDs for the secondary and tertiary pumps, pumping energy can be reduced significantly for most of the time even during the peak summer season.

Prior to the walk-through survey conducted on the 2nd of April 2008, a common practice was to operate 3 or more big secondary water pumps round the clock along with the seven tertiary pumps. Furthermore, these pumps operated at full speed as their VFDs were nonfunctional. On a typical winter day, with single chiller and three secondary main building pumps in operation, the average temperature differential across the chiller of 6.6°C was nearly four times higher than the temperature differential across the secondary headers. This indicated that the water flow in the secondary and tertiary circuits was four times higher than the required flow.

Between August 2008 and August 2009 five different schemes were implemented by manually controlling the flow in secondary and tertiary circuits by reducing number of secondary pumps and operating frequencies of secondary and tertiary pump motors. Reductions were achieved gradually. During the lean season, (November to March) the daily energy consumption of the secondary pumps reduced from 12519 to 2732 kWh/d and same for the tertiary pumps reduced from 5028 to 2679 kWh/d. Thus average energy reduction for the secondary and tertiary pumps are well over 12136 kWh/d. The operating pumps during this period were 2 main building secondary pumps with a frequency ranging between 30 and 35 Hz. For the peak summer months, frequencies of the operating pumps were reduced without reducing the number of pumps. The pumps in operation were 4 secondary main building pumps along with 2 secondary Carrefour pumps. The average actual power demand for the month of August 2009 of 437.4 kW was 46.7% less than the baseline. Assuming that the enforcement of the measures is consistent and achievable, the average power demand for different months has been estimated based on the actual average daily number of chillers in operation (Al-Hadban et al., 2010). And it is estimated that optimization of chilled water flow can lead to a combined direct and indirect savings of 4544.8 MWh/y.

Energy Efficient Cooling Production

Energy efficient cooling production in a central chilled water system can be achieved by the combined implementation of energy efficiency and energy conservation measures. Increasing the loading of chillers is an important energy efficiency measure while keeping the supply chilled water temperature higher during non-occupancy period, and low demand season is an important energy conservation measure.

In the case of cooling systems with centrifugal chillers, part-load operation deteriorates their energy performance. In addition, the temperature of chilled water leaving the chiller ($T_{ws}$), affects efficiency. Raising the value of $T_{ws}$ at periods of low cooling demand improves the performance of the chiller (Elsherbini et al., 2007). Thus, improving the chillers loading close to 100% and keeping the $T_{ws}$ higher would help to increase the energy efficiency of the cooling production system or minimize its power rating (PR). This means that the power required by the chiller per unit of cooling will be less. Furthermore, these two measures help the cooling production system to deliver the required cooling with reduced number of operating chillers, and since reduction in the number of an operating chiller is associated with the reduction in its auxiliaries such as primary chilled water pump, condenser water pump and the cooling tower fan. These auxiliaries together have a connected load of 143.2 kW/chiller.

Chiller Loading. Based on the advice of KISR team, chiller loading was significantly improved both for the lean and peak demand seasons. During the lean season, based on the data of February 2008, as the base case, the average chiller loading was 75.0%, while the loading improved to 91.3% in November 2008. Likewise, for the peak demand season, loading improved from 81.4% in August to 89.1% in September. The monthly average loading of the chillers for January to August 2008 as baseline and from September 2008 onwards after implementing the energy efficiency measures is shown in Fig. 7. An improvement in weighted average chiller loading of close to 6%, from 79.3 to 85.2% was achieved.

Supply Chilled Water Temperature. The new operation strategy increased average $T_{ws}$. The increase in average $T_{ws}$ was achieved mainly by operating the chillers at higher temperatures during the no occupancy period. During the lean season, based on the data of February 2008, as the base case, the daily average $T_{ws}$ was increased from 6.1 to 8.1°C in November 2008. Likewise, for the peak demand season, average $T_{ws}$ was increased from 5.5°C in August to 6.0°C in September. The monthly average $T_{ws}$ of the chillers for January to August 2008 as baseline and from September 2008 onwards after implementing the energy efficiency measures is shown in Fig. 8. An increase in weighted average $T_{ws}$ of 0.82°C, from 5.79 to 6.61°C was achieved. Results of an analytical study of a Macquay centrifugal chiller with a water cooled condenser for an incoming condenser water temperature of 26.7°C showed an increase of 1.8% in chiller power rating for every degree Celsius drop in $T_{ws}$ (Hajiah et al, 2006).

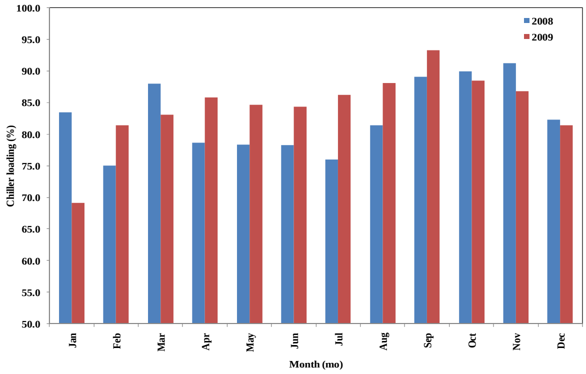


Fig. 7. Average chiller loading.

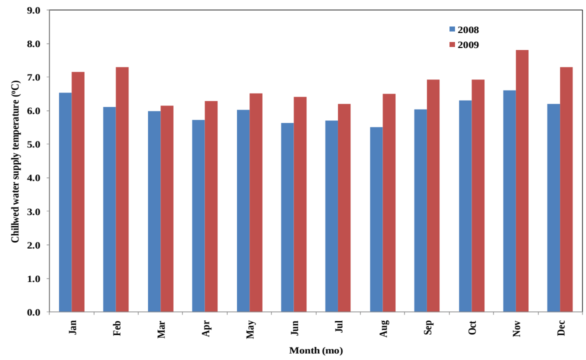


Fig. 8. Average chilled water supply temperature.

Using the monthly average of number of chillers in operation and the respective rise in $T_{ws}$ and chiller PR, the monthly reduction in energy consumption by the cooling production system has been estimated (Al-Hadban et al., 2010). By increasing the $T_{ws}$, the annual energy consumption of the cooling production system was reduced by 310 MWh/y. In addition, an increase in chiller loading combined with the reduction in cooling demand has reduced the chiller hours by 2933. The expected energy reduction in the auxiliaries of the chillers was 420 MWh/y. These measures reduced the annual energy consumption by 790 MWh/y.

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Lighting

Although the lighting system in the Avenues is energy efficient and of the latest technologies, there is room for achieving no cost savings simply by benefitting from daylight. Implementation of TDC for the fluorescent tubes with a load of 74.5 kW in the hallways achieved direct and indirect savings of 387.5 MWh/y (Al-Hadbn et al., 2010). Additional direct energy savings of 61.0 and 133.3 MWh/y can be achieved, if the recommended measures, the replacement of 50-W halogen lamps in the restrooms and washrooms by their equivalent 35-W energy saver halogen lamps and installation of occupancy sensors in the internal and service corridors, respectively would be implemented. Implementation of TDC along with the recommended energy conservation measures if applied, the total annual savings of 581.8 MWh/y can be achieved.

## CONCLUSIONS AND RECOMMENDATIONS

- Phase 1 of the Avenues mall was built using environment friendly techniques with maximum use of natural light and a very energy efficient envelope. Also, it has energy efficient A/C and lighting systems which are operated through a state-of-the art building automation system. Prior to energy audit, the peak power demand of phase I was close to 15 MW and its annual energy consumption was 84000 MWh/y.
- Implementation of TDC for AHUs using the existing facilities in the BAS was found to be simple and trouble free. Out of a total 108 AHUs with a connected load of 1752 kW, TDC was implemented in 81 AHUs altogether with a connected load of 1279 kW. The annual energy savings achieved due to closure of the fans and reduction in cooling demand are 2699 and 1557 MWh/y, respectively. Thus, the total savings of 4256 MWh/y were achieved leading to a reduction of 5.1% in the baseline annual energy consumption. These savings could be increased to 7757 MWh/d by ensuring a better implementation of TDC. Furthermore, TDC implementation not only helped energy conservation while maintaining the comfort conditions during the occupancy period, it also avoided extremely lower temperatures during the non occupancy period.
- Chilled water distribution system comprising of primary, secondary and tertiary pumps with a connected load of 1298 kW is fairly energy intensive. It accounts for 13.5% of the VAC system load and has a PR of 0.18 kW/RT, which is over two and half times higher as compared to its value as per the revised energy conservation code. Furthermore, these numbers related to the percent share and the PR on the daily, monthly and yearly basis are considerably higher. Recognizing the importance of optimizing the chilled water flow was therefore obvious. Manually operating the secondary and tertiary pumps as per the proposed schemes during the winter and summer season can lead to direct and indirect savings of 3979.7 and 565.1 MWh/d

respectively. The total yearly savings of 4544.8 MWh/y can be achieved. Also, a minimum one fourth of the maximum pumps power, i.e., 270 kW, can be reduced during the peak power demand period. Nevertheless, considering the importance of chilled water distribution both for comfort quality and the energy efficiency, a complete overhaul of the system is recommended. It may include replacement of secondary pumps with smaller pumps in addition to complete automatic operation of variable frequency drives.

- Implementation of energy efficient cooling production resulted in improving the average chiller loading by 6% from 79.3 to 85.2%, and an average increase in supply water temperature of 0.8$^o$C. By increasing the $T_{ws}$, the annual energy consumption of the cooling production system was reduced by 310 MWh/y. In addition, an increase in chiller loading combined with the reduction in cooling demand has reduced the chiller hours from 22055 to 19887 for the first 8 mos of each year. Extending this savings for the complete year in chiller hours was 2933. The expected energy reduction in the auxiliaries of the chillers was 420 MWh/y. These measures reduced the annual energy consumption by 730 MWh/y.
- Lighting system is energy efficient and incorporates many latest technologies. Benefitting from daylight and applying TDC in the public areas, reduction in annual energy consumption of 387.5 MWh/y was achieved by turning off lights and reducing the associated cooling load. More importantly, this could reduce the peak period power demand by 74.5 kW. Additional reduction of 195 MWh/y can be achieved by deploying cost-effective energy conservation measures such as installation of occupancy sensors in the internal and service corridors and replacement of 50-W halogen lamps in the restrooms and washrooms by their equivalent 35-W energy saver halogen lamps. Furthermore, it is recommended to perform regular semiannual cleaning of luminaires in order to ensure their performance, and increase illumination levels in the rotundas during the night time which are presently insufficient.
- The energy savings achieved through implementation of various EEO&MS are summarized in Table 1. By realizing total energy savings of 9919 MWh/y, equivalent to a percentage reduction of 11.8% in the annual energy consumption and a financial benefit of 19838 KD/y, to the Mabanee and company S.A.K, the project achieved its goal comprehensively. More importantly, the project achieved the national financial and environmental benefits as follows:
  - Reduction in peak power demand of 345 kW, equivalent to a reduction in power generation and transmission cost of KD 160,000,
  - Reduction in annual electricity subsidy of KD 372000/y, and
  - Reduction in annual $CO_2$ emissions of 6940 t/y.
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Table 1. Summary of Savings Achieved

| SL No. | EEO & MS | Savings | |
|---|---|---|---|
| | | Peak Power (kW) | Annual Energy (MWh/y) |
| 1 | Time-of-Day Control VAC System | Nil | 4256 |
| 2 | Optimization of Chilled Water Flow | 270 | 4545 |
| 3 | Energy Efficient Cooling Production | Nil | 730 |
| 4 | Lighting | 75 | 388 |
| | Total | 345 | 9919 |

Nevertheless, these achievements should be taken as a first step toward implementing energy EEO&MS, as there is substantial scope for further reductions in the power, energy and water demand of the mall besides ensuring high quality comfort conditions. The proposed recommendations should therefore be considered seriously.

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